Direct-To (D2)
General Description
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Final
General Description

Direct-To (D2)

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AATT OPERATIONAL CONCEPT FOR ATM – YEAR 2002 UPDATE

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ACKNOWLEDGEMENT

The majority of the descriptions presented in this document have been taken directly from NASA documents shown in the bibliography. Minor modifications have been made to the text to provide readability. The Direct-To Functional Flow chart has however been independently developed for this description. This approach to the development of this document was taken in order to remain faithful to the efforts that are presently being undertaken by the NASA AATT Project Office, the D2 Tool Developers and the associated NASA AATT contractors.

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AATT DIRECT-TO (D2)
GENERAL DESCRIPTION

1. DESCRIPTION

Purpose
Provide clearance advisories for time- and fuel-saving direct routes.

Users
En Route radar controllers

Field Sites
Fort Worth Air Route Traffic Control Center (ARTCC)

Operational Results
- Potential for a Direct-To tool was discovered unexpectedly during field tests of the CTAS Conflict Probe and Trial Planner functions at Denver ARTCC (Sept. 1997) and Fort Worth ARTCC (Nov. 1998).
- Controllers pointed out a preferred use of the Trial Planner: searching for conflict-free direct routes.
- Potential savings in flying time for Fort Worth ARTCC airspace has been estimated at approximately 1800 minutes per day, or about 2.5 min. per Direct-To clearance advisory.
- An analysis of Direct-To at other ARTCC facilities in the NAS shows similar potential for savings.
- Operational field test conducted during the summer of 2000 at Fort Worth ARTCC.

Overview
The insight that led to the design of the Tool originated with experience gained in evaluating the Conflict Probe/Trial Planner (CPTP) built into the Center TRACON Automation Systems (CTAS). During the field test of CPTP at the Denver Center in the Fall of 1997, controllers would usually attempt to resolve conflicts predicted by the Probe by trial-planning resolution trajectories that led from the conflict aircraft's current position to a down-stream fix along the aircraft's flight plan. In about 20% of such attempts, they succeeded in finding trajectories direct to a fix that resolved the conflict. Thus, when this method was successful, the solution had the additional advantage of reducing the path distance to fly to the destination. It was a surprise finding that this strategy was so often successful. In the Denver Center tests, only aircraft that were "fortunate" to have been identified as being in conflict had the potential to benefit from path shortening direct-to fix trajectories. This finding suggested the following hypothesis: since conflicts are random events, there must exist a similar percentage of non-conflict aircraft that could reduce their path distances by direct-to fix trajectories. Armed with this knowledge, controllers at a follow-on test of CPTP at the Fort Worth Center used the Trial Planner to manually search for non-conflict aircraft that could benefit from direct-to fix trajectories. Through trial and error with CPTP they found many aircraft, especially departures from DFW, that were eligible for path shortening direct-to fix trajectories.

While effective for finding and resolving conflicts and conflict probing direct routes for any aircraft selected by the controller, CPTP lacked the ability to automatically identify all aircraft eligible for direct-to routes and to determine and display the corresponding time savings. To aircraft operators, time saving, which accounts for the effect of winds, and not necessarily path length saving, is the appropriate measure of flight efficiency.

In order to explain the need for an automated method of generating direct-to clearances, it is necessary to review briefly the basic structure of flight plans and the routes derived from them. Typically, for an airline flight between major airports, a flight plan consists of three types of concatenated route segments: a standard instrument departure (SID) route, an en route path, and a standard terminal arrival route (STAR). The en route path is defined by a sequence of three letter identifiers for fixes, five letter identifiers for route intersections, and airway identifiers. The geographical coordinates of waypoints are also acceptable entries in a flight plan and may either be specified by their latitude/longitude coordinates or their polar coordinates (angle and distance) relative to a named fix. The latter method is referred to as a fix radial distance (FRD). An example of a typical flight plan between Dallas/Fort Worth and Boston is given in Figure 1. For reference, great circle route between DFW and BOS is also shown.

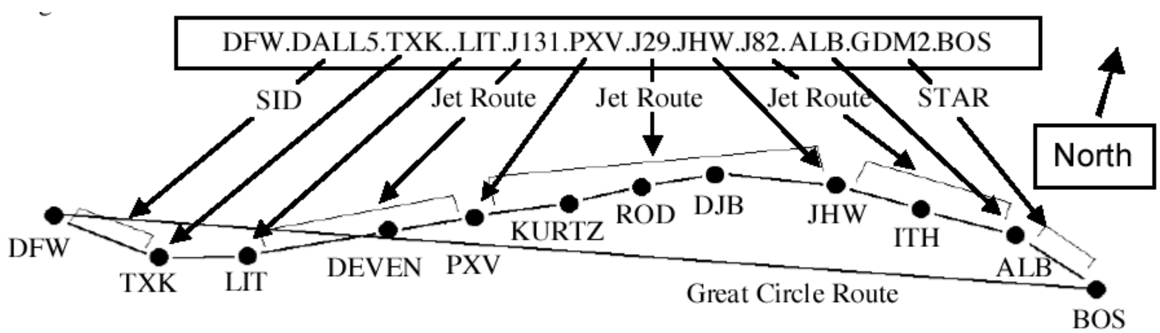

Figure 1. Decomposition of a flight plan into its waypoints and horizontal route segments.

Since most flight plans are generated by the flight planning services of airlines before being sent to the air traffic control system, it is not always obvious to a pilot or controller if the efficiency of the flight route can be improved after departure. Because of the significant effect of spatially varying wind fields on time to fly along a specified route, a direct-to clearance to a down-stream waypoint that bypasses one or more route segments in the flight plan could either increase or decrease the time to fly to the destination. Except in obvious situations, neither pilot nor controller has reliable information at hand to guide them in deciding whether a direct-to clearance will increase or decrease flight efficiency. Furthermore, in transition airspace near a terminal area, an aircraft deviating from a departure or arrival route could cause problems and disrupt the orderly flow of traffic.

The Direct-To Controller Tool identifies aircraft that can save at least one minute of flying time by flying direct to a down-stream fix along its route of flight. A list ordered by time savings is presented on a display for the controller, showing the call sign, equipment suffix, time savings, Direct-To fix, wind-corrected magnetic heading to the fix, and conflict status for eligible aircraft within a controller's sector. A point-and-click button next to the call sign on the Direct-To List activates a trial planning function that allows the controller to quickly visualize the direct route, choose a different fix if necessary, and automatically input the direct route flight plan amendment to the Host computer. The Direct-To List is strictly advisory and the controller may issue the direct route as advised, modify the direct route or remove the advisory depending on traffic conditions or other factors. The Direct-To Tool was implemented in CTAS by adding one additional process to the existing software architecture for the TMA. Figure 2 illustrates the D2 display. A bibliography of D2 related documents is presented as Appendix A.

Over 35 controllers from 9 different en route centers participated in the development of the Trial Planner, which is an integral part of the Direct-To user interface. A team of controllers from Fort Worth ARTCC has participated in the development of Direct-To from its inception in 1998. Controller simulations of Direct-To at NASA Ames (August 1999) and the FAA William J. Hughes Technical Center (February 2000) have resulted in positive feedback from controllers and airspace users. Controller workload for flight plan amendments is reduced from 20+ head-down keyboard entries to 2-3 head-up mouse clicks. Controller productivity is improved as well since Direct-To advises only timesaving direct routes.

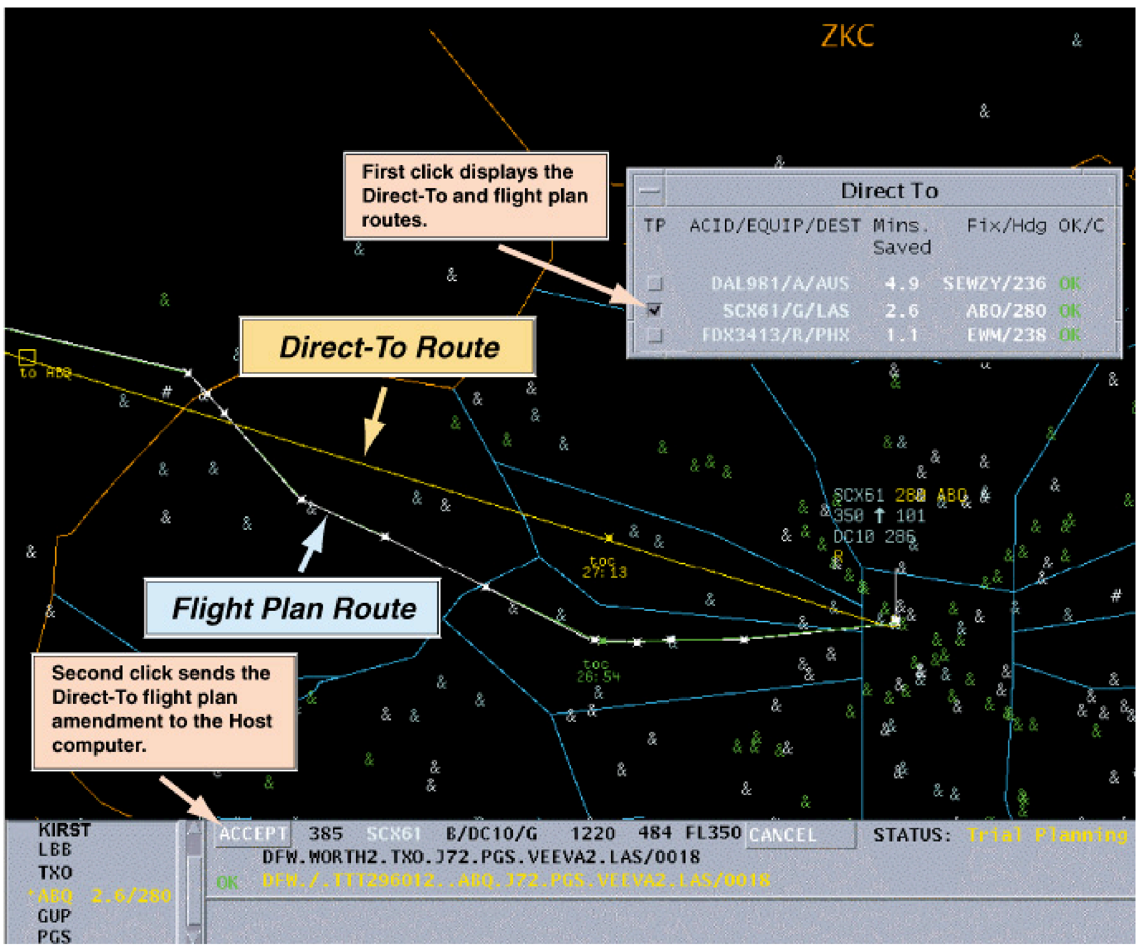

Figure 2. D2 Display

Accounting for the wind field is an essential element of the Direct-To algorithm. CTAS receives hourly updates of the National Oceanic and Atmospheric Administration's Rapid Updated Cycle atmospheric model, which represents the highest accuracy wind model currently available. For each candidate aircraft, CTAS computes the time to fly to the Direct-To fix along the flight plan route and the time to fly direct to the fix. If the savings along the direct route is greater than one minute, the clearance advisory is added to the Direct-To List.

Candidate Direct-To fixes are restricted to be within a limit rectangle to prevent aircraft from deviating significantly from their planned route. The limit rectangle for ZFW is 600 miles (North/South) by 1,000 miles (East/West), centered at the Dallas-Fort Worth airport. An alternative to the rectangle method is to limit Direct-To fixes to the "home" Center and all adjacent Centers that surround the "home" Center. For large airports within the limit region where a direct route to the airport is not feasible, Direct-To fixes are limited to an appropriate fix along the arrival route to the airport. Figures 3 and 4 illustrate operational demonstrations of the Direct-To tool at Denver Center in September 1997 and at Ft. Worth Center in November 1998.

Figure 3. Denver Center

Figure 4. Ft. Worth Center

2. OPERATIONAL CONCEPT

The controller interface for the Direct-To Tool has been designed to be accessible from the controller's display monitor. It employs a graphical user interface similar to software running on workstations and personal computers. With the Direct-To Tool, the controller selects items from menus and sends flight plan amendments from the controller display to the Host computer using point-and-click actions executed with a mouse or track ball. Experience gained from field tests of the CTAS Conflict Probe/Trial Planner established strong controller preference for a point-and-click graphical user interface that minimizes, if not altogether eliminates, the time-consuming keyboard entries currently in use. An efficient and controller-friendly interface not only will ensure controller acceptance of the Direct-To Tool but also will increase the likelihood that controllers will use the Tool when the opportunity arises. For a Tool such as this, whose use is not safety-critical but is essentially voluntary, a friendly and low workload interface provides the main incentive for controllers to use it. The Tool interface consists of the Direct-To List, point-and-click executable commands, and graphical display of trajectories.

The Direct-To List appears as a panel on the controller's display and is illustrated in Figure 5. The first, and most important, items in the List are the aircraft call signs (ACIDs) of all aircraft which the algorithm has determined are eligible for direct-to clearances. Only those eligible aircraft currently “owned” by the controller of a specific sector are displayed in the panel. The eligible ACIDs, if there are more than one, are ordered by the amount of potential time saving, with the ACIDs having the highest time saving shown at the top of the List. The List is refreshed and reordered every 12 seconds. This time interval corresponds to the refresh cycle of trajectory computation in CTAS. In the typical evolution of this List, an aircraft initially appearing near the top of the List migrates gradually toward the bottom with each update cycle. The aircraft is removed from the List either when the potential time saving has become less than the threshold value of one minute or as a consequence of the controller having issued a direct-to clearance that reduces the time saving to less than one minute.

In addition to the ACID, the List contains other essential information to assist the controller in deciding whether to issue a direct-to clearance for an eligible aircraft and, if so, what type of clearance to issue. Figure 5 shows a screen photo of a Direct-To List containing three eligible ACIDs.

Figure 5. Screen Photo of D2 List Panel

As illustrated in Figure 5, the aircraft equipage code and the destination airport identifier follow the ACID and are separated from each other by slashes. The equipment identifier tells the controller the type of navigation equipment carried by that aircraft. Seventeen types, each identified by a letter code, are recognized in air traffic control. The three shown in Figure 5 (G, E, A) refer to GPS equipped, flight management system equipped, and conventionally equipped, respectively. The controller uses the equipage code to determine the type of clearance to issue. For example, an A-equipped aircraft, the least sophisticated of the three, will generally require the controller to issue both a heading direction and a navigation fix as part of the direct-to clearance. On the other hand, for aircraft with E, G or certain other equipage codes, the controller need specify only a navigation fix to the pilot when issuing the direct-to clearance.

The next field gives the amount of time saving, in minutes, provided by a direct-to trajectory, compared to the currently planned trajectory. When there are several aircraft in the List, comparison of time savings helps the controller prioritize the order in which to issue direct-to clearances. For example, during periods of high workload, he/she may only have time to issue

one or two direct-to clearances. In that case, issuing direct-to clearances to aircraft with the highest potential time savings will maximize the controller's productivity.
The next field gives the identifier of the direct-to fix computed by the algorithm and the heading to that fix, separated by a slash. As explained in the preceding section, the direct-to fix is always a fix along the route of flight and located down-stream from the current position of the aircraft. The heading angle is the magnetic heading and is corrected for wind speed and direction. Thus, it is the magnetic heading that the aircraft must fly starting at the current position in order to be on course to cross the fix. The fix identifier and the heading provide the information the controller needs to issue the clearance to the pilot.

The next to last field gives the predicted conflict status of the aircraft along the proposed direct-to trajectory. An "OK" indicates no conflict, whereas a "C" indicates a conflict is predicted. Furthermore, on the color monitor where the List is displayed, the conflict status symbols are color-coded to enhance recognition, with "OK" drawn in green and "C" in red. Observation shows that aircraft are predicted to come into conflict along the direct-to route infrequently, and that only about one in ten aircraft ever show a conflict at any time while they are on the List. When several aircraft appear on the List, some with and some without conflicts, the controller could initially skip aircraft with conflicts and work only with the conflict-free aircraft. Then, when the conflicts have cleared, as they frequently do after a short time, the controller can consider issuing direct-to clearances, to these, now conflict-free, aircraft.

In addition to showing predicted conflicts for the direct-to routes, the List also uses a symbol, a red asterisk (*), located to the left of the ACID, to indicate if the direct-to eligible aircraft is in conflict on its current flight plan route. In Figure 5, asterisks indicating such conflicts are shown for COA1914 and COA1494, the second and third ACIDs on the List. The asterisk essentially serves to cross-reference ACIDs, which are simultaneously present in the Direct-To List panel and the CTAS Conflict Prediction panel. This is illustrated in the screen photo of the controller's display shown in Figure 6, where both panels are found at the top of the photo. The Conflict Prediction panel is the controller's interface to the CTAS Conflict Probe. It lists all pairs of aircraft in a region of airspace, which the conflict search algorithm predicts will violate specified separation criteria within a search time horizon.

Checking for the presence or absence of the two categories of predicted conflicts helps the controller make the most timely and productive choice of the next direct-to eligible aircraft. To demonstrate how this is done, consider the situation illustrated in Figure 5 by the third aircraft in the List, COA1914. This direct-to eligible aircraft is predicted to be in conflict along its current (non-direct) route, as indicated by the asterisk, but is predicted to be conflict-free along the proposed direct-to route. A controller recognizing this situation would have a high incentive to choose this aircraft since a direct-to route amendment issued to this aircraft not only reduces flight time but also resolves the predicted conflict in a single clearance. For the situation where both categories of conflict are predicted, as for COA1494 in Figure 5, the choice is not as unambiguous as was the previous case but still may be worthy of investigation by trial planning. For example, the controller may be able to resolve the conflict by choosing a different direct-to fix or a different cruise altitude and still achieve some reduction in flight time.

The last field is a square button, used to delete a direct-to entry from the Direct-To List panel. For example, a controller may wish to delete an aircraft from the List because that aircraft's route includes a necessary detour around a region of severe weather.

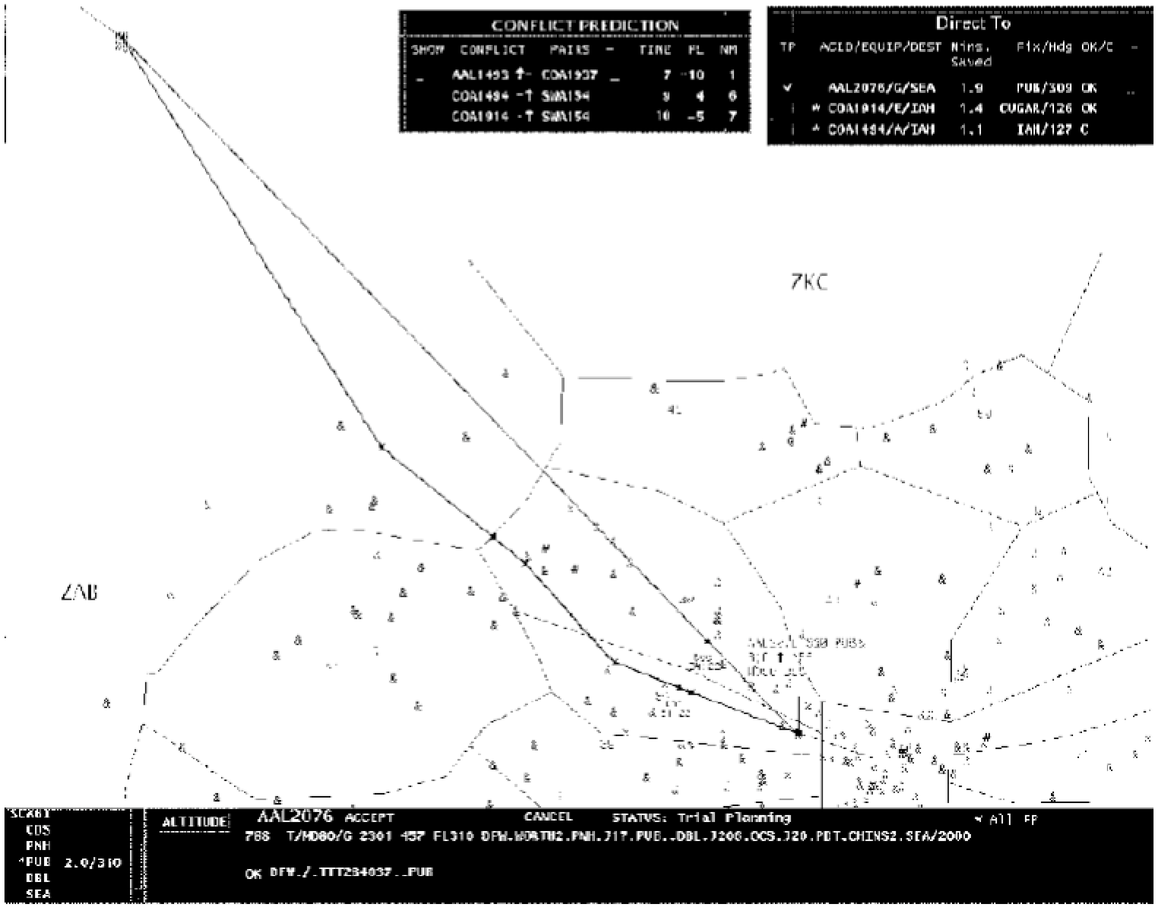

Figure 6. Screen Photo of Direct-To Display

Controllers who have evaluated the List in shadow mode with live traffic from the Fort Worth Center do not consider the conflict status as the definitive accept/reject criterion for issuing a direct-to clearance. Instead, they base their decision to issue a direct-to clearance on their overall assessment of the traffic situation, their knowledge of the airspace as well as the conflict status shown in the List. These controller opinions reflect a basic characteristic of this support tool, namely that the information provided by the Tool is advisory only and as such is not a substitute for good controller judgment. Thus, the controller should always augment the advisory information provided by the Tool with analysis of the traffic situation before issuing a direct-to clearance.

In order for the controller to access additional information on aircraft in the List and to simplify making flight plan amendments, the Direct-To List and the CTAS Trial Planner have been interconnected through an on-screen button in the Direct-To List. The button, in the form of a small square, is located to the left of each ACID in the List [see Figure 5]. The button is a select/deselect switch that puts the corresponding aircraft into the trial planning mode when it is clicked with the mouse into the select position. A check mark, as shown for the first ACID on the List in Figure 5, indicates that the corresponding aircraft has been selected for trial planning.

The Trial Planner provides the controller with special tools and interactive graphics for managing the trajectories of aircraft in climb, cruise, and descent. With few exceptions, all interactions with the Trial Planner are conducted by point-and-click actions with the mouse (or trackball). Thus, “head down” keyboard entries are almost entirely eliminated. Conflict probing using the CTAS conflict detection algorithm is an integral part of the Trial Planner. The Trial Planner allows the controller to put any aircraft, not just aircraft in the Direct-To List, in trial planning mode. The Conflict Probe/Trial Planner has been evaluated in field tests at the Denver Center and the Fort Worth Center.

When the controller selects an aircraft from the Direct-To List for trial planning by clicking on the select button, additional information appears on the screen. A representation of the controller’s display covering the North-West quadrant of the Fort Worth Center airspace is shown in Figure 6 when trial planning a direct-to route for flight AAL2076. The ampersands (&) designate the location of other traffic. Both the flight plan route and the direct-to route are displayed for this flight. A panel at the bottom of the screen displays the complete flight plan. At the bottom left, a menu lists the fixes and waypoints in the flight plan that may be used as alternate direct-to fixes. The direct-to fix selected by the algorithm (PUB) is marked by an asterisk in the menu. The time saving (2.0) and the heading to the fix (310) are also displayed adjacent to the fix. The area labeled altitude at the bottom left and adjacent to the waypoint menu is a menu button for selecting altitude trial planning. It is clicked on when an altitude amendment is required in addition to the direct-to route amendment.

To the right of the altitude button are several lines of information pertaining to the aircraft selected for Direct-To trial planning. The first line contains the ACID and buttons to Accept and to Cancel trial planning. The second line contains the current flight plan. The third line (shown blank in the figure) is reserved for displaying the ACID and its flight plan of an aircraft predicted to be in conflict with the aircraft selected for trial planning. The bottom two lines pertain to the trial plan. The first bottom line contains the trial Flight Plan, including the proposed direct-to route amendment. The second bottom line, (shown blank in the figure) would show the ACID and flight plan of an aircraft predicted to be in conflict with the selected direct-to aircraft along its trial direct-to route. Both conflict lines are blank in the figures because neither type of conflict was detected for the trial direct-to aircraft. Both the trajectory display graphics and the information in the trial planning panel are identical to that in the CTAS Conflict Probe/Trial Planner system. If a conflict is predicted along the direct-to route, then the conflict ACID together with pertinent conflict information is also included in the flight plan panel (not shown in Figure 6 because no trial planning conflicts were found). This information is identical to that in the CTAS Conflict Probe/Trial Planner display.

The content and arrangement of the information shown on the screen has been designed to tell the controller at a glance whether to accept or reject the direct-to route amendment. If his/her decision is to accept, then the controller need only click on the “accept” button in the panel in order to amend the flight plan. This action sends the direct-to flight plan amendment message from CTAS into the Center’s Host computer. Under normal circumstances, the only actions required by the controller in executing a direct-to route amendment consist of two consecutive mouse points and clicks. This simple procedure contrasts sharply with the multiple keyboard entries required by the current operational system to execute direct-to route amendments, referred to as the 6-7-10 amendments, route key amendments or field 10 amendments.

The Trial Planner provides the ability to evaluate and select any one of numerous alternatives to the trajectories generated by the direct-to algorithm. For example, the controller can select any fix/waypoint along the route of flight as the direct-to fix by clicking on the appropriate fix identifier in the fix/waypoint menu. The Trial Planner will check the new direct-to trajectory for conflicts and update the corresponding time savings, fix identifier and heading angle displayed in the Direct-To List. Controllers found the ability to easily change the direct-to fix to be a useful feature, especially when the direct-to trajectory shows a conflict. These conflicts can sometimes be resolved by choosing a direct-to fix that is either up-range or down-range of the advised direct-to fix or it may be resolved by creating an auxiliary waypoint, or adding an altitude amendment. In summary, the integrated capabilities of the Direct-To List and Conflict Probe/Trial Planner provide an effective environment by increasing controller productivity and reducing workload.

3. FUNCTIONAL FLOW

Figure 7 illustrates the detailed functional flow of D2 operating in the ARTCC and depicts the functional interfaces with external data sources. The input/output sources, appearing in double boxes, are shown in the figure. The major functions within D2 are:

- Data Acquisition and Processing
- Aircraft List Management
- Trajectory Generation
- Time Savings Estimation
- Conflict Detection
- Trial Planning
- Display Message Processing

The narrative contained in the following section provides adequate description for the D2 functional flow and for the D2 software architecture combined. A flow chart of the algorithm for generating the direct-to eligible aircraft and the direct-to fixes is shown in Figure 8. The algorithm requires access in real time to the set of all aircraft being actively tracked by the radar sensors and surveillance system of the Center where the Tool is installed. For each tracked aircraft, its identification symbol, together with its current position, velocity, altitude, flight plan and aircraft type must be provided at the update rate of 12 seconds which matches the track update rate of the Host computer. This information is available in CTAS when it is installed at a Center.

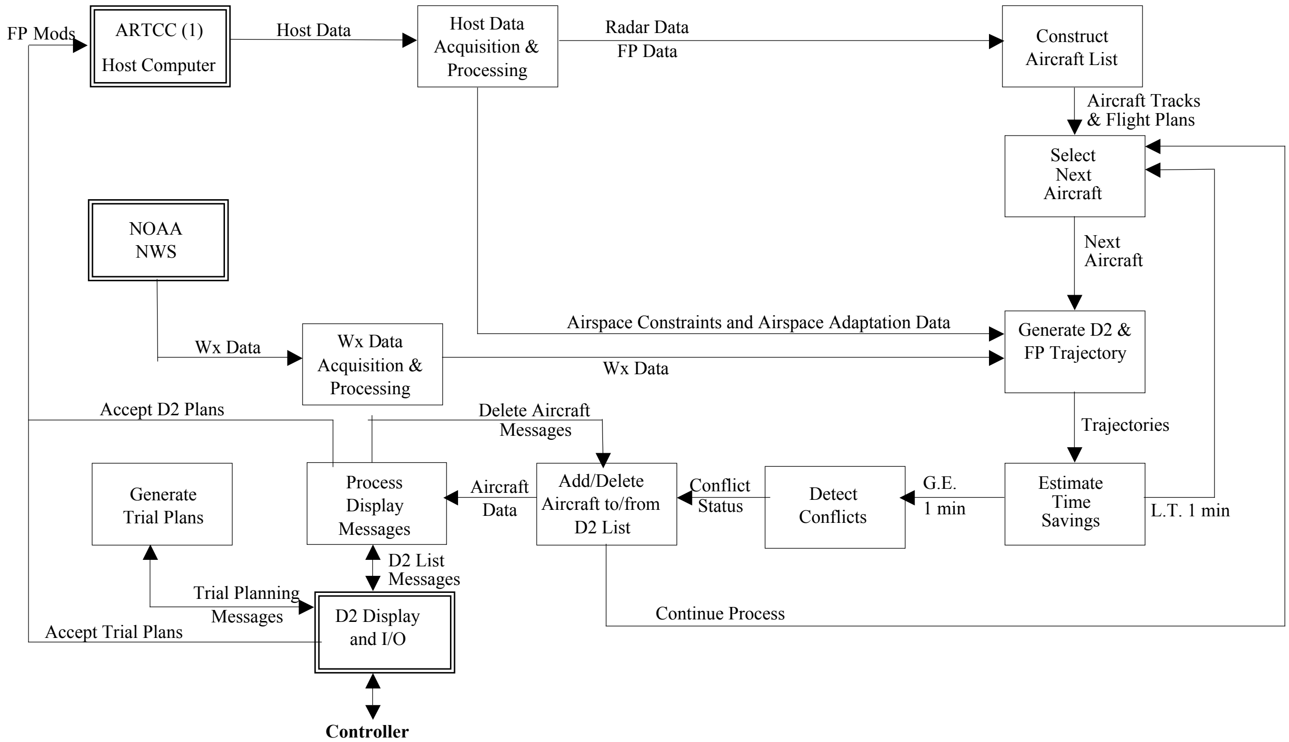

Figure 7. D2 Functional Flow Diagram

The algorithm tests each aircraft in this set sequentially, repeating the test at 12-second intervals, which is standard for CTAS's en route tools. The first test after an aircraft has been chosen from the set determines if its destination airport is inside or outside of the limit rectangle. If outside, it tests each fix/waypoint on the flight plan in succession, starting at the next waypoint to which the aircraft is headed, to find the one closest to a boundary of the limit rectangle, thereby establishing the direct-to fix. If inside, it retrieves the direct-to fix from the adaptation database by specifying the destination airport and arrival route. Then the algorithm requests the CTAS 4D trajectory synthesizer to generate two trajectories to the computed direct-to fix, one along the flight plan route, the other along the direct-to route. The times to traverse each route, obtained from the 4D trajectories, are compared. If the direct-to route saves at least one minute, that aircraft's ID will be added to the controller's Direct-To List as described in the next section. The one minute criterion was chosen because it represents the quantum of time saving considered significant in airline operation, and also to limit the number of aircraft in the List. If the time saving is less than one minute, the aircraft is eliminated, but it will be re-tested again in the next update cycle. In the last step, an aircraft that has passed the time saving test successfully is tested for predicted conflicts by CTAS's Conflict Probe/Trial Planner function against all other actively tracked aircraft that are known to CTAS [8,9]. Following the recommendation of a controller who advised on the design of the interface, it was decided to include direct-to eligible aircraft with predicted conflicts in the List. The rationale behind this design decision is explained in the next section. Here it should be mentioned that the conflict probing is performed with the conflict alert parameters set to 12 nmi horizontal for all aircraft and 4,000 ft vertical separation for transition aircraft. These are significantly larger than the regulatory limits of 5 nmi and 2,000 ft.

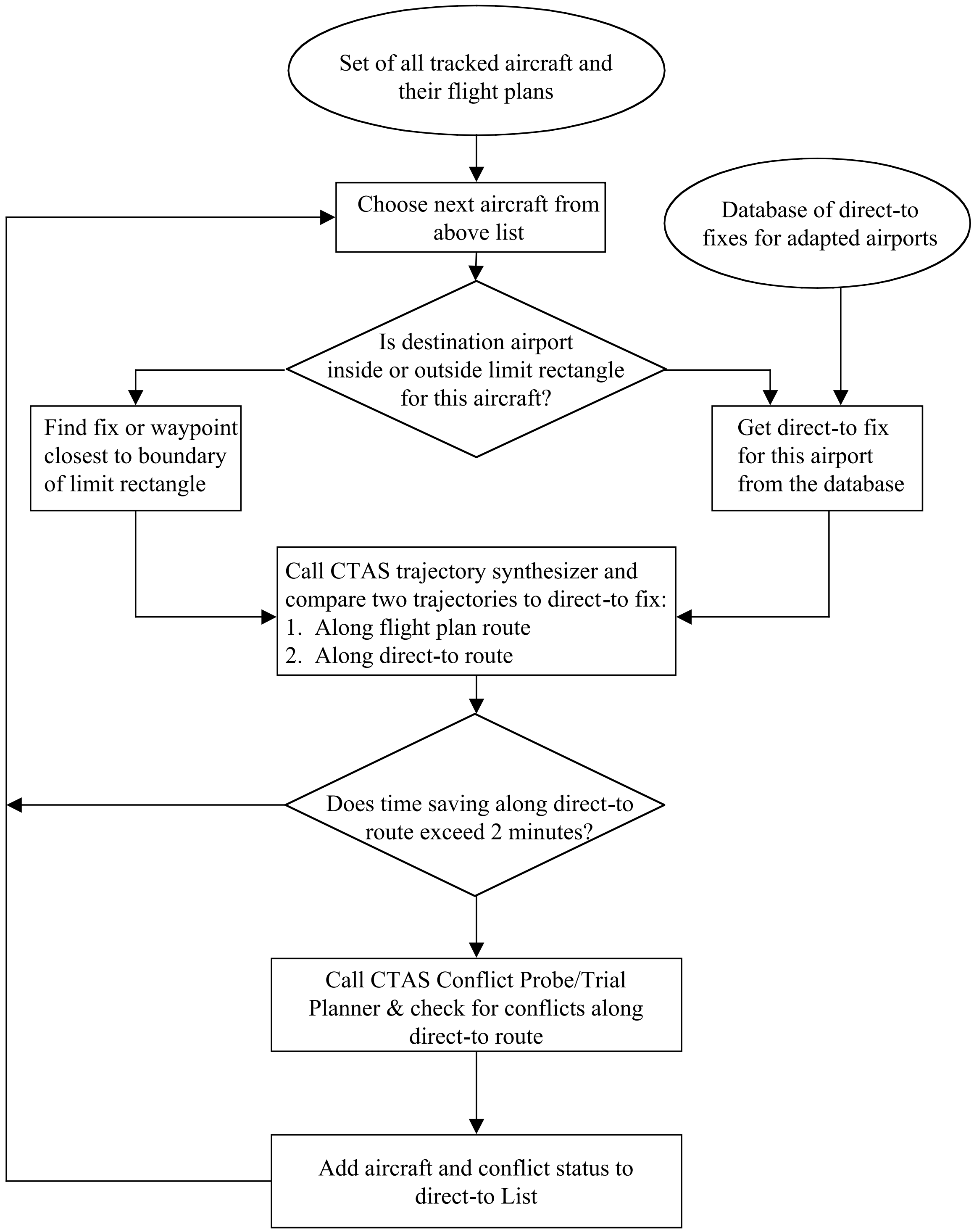

Figure 8. D2 Algorithm Flow Chart

The extra margin gives the controller, who is responsible for issuing the clearance, increased confidence that the direct-to route will be problem free for down-stream controllers. In the CTAS Conflict Probe, the alert parameters are adjustable and therefore can be adapted to meet the requirements of each facility. The newly discovered direct-to eligible aircraft, together with its time saving, direct-to fix identifier; conflict status and certain other information are now added to the Direct-To List.

The algorithm as implemented in CTAS can accommodate two enhancements that will further increase the efficiency of the direct-to trajectories. One is to extend the search for the best direct-to fix to more than one fix. By computing trajectories to several candidate fixes lying within the limit rectangle, it is possible to identify the fix that produces the greatest time saving. The second enhancement is to evaluate the effect on time saving when the cruise altitude is changed one or more levels above and one or more levels below the current cruise altitude. This will identify the altitude level where winds are the most favorable. While these enhancements will increase the computational load, they are considered feasible to implement, because the multiprocessor architecture of CTAS's trajectory engine was designed to handle this load and is doing so successfully in supporting the operation of other CTAS Tools with similar requirements.

APPENDIX A: BIBLIOGRAPHY

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